RUTIN NANOPARTICLE-DRIVEN FORMULATION FOR ENHANCED BIOLOGICAL AND ENVIRONMENTAL APPLICATIONS

SYNOPSIS

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1. INTRODUCTION

Rutin, a type of flavonoid, possesses properties that are antimicrobial, antioxidant, antipsoriatic and photoprotective in nature and it has drawn attention for potential therapeutic applications. On the other hand, its poor solubility, stability and bioavailability limit its chemical potency. Enhancing the solubility and bioavailability of rutin through nanotechnology is a promising approach, enabling more effective therapeutic applications. This research aims to synthesize rutin-loaded nanoparticles (RNPs) and formulate a topical delivery system for the treatment of antimicrobial and photocatalytic activities. Rutin is present in variety of plants and it is a naturally occurring flavonoid glycoside. It is composed of the flavonoid *quercetin* and the disaccharide *rutinose*. Rutin has several beneficial properties, making it an essential bioactive compound in medicinal and therapeutic applications [1].

1.1 Nanoparticle Formulations of Rutin

Rutin's low solubility in water limits its bioavailability. Nanoparticle formulations are used to enhance its absorption and therapeutic effects. Some common types of rutin nanoparticles include: liposomal nanoparticles composed of phospholipid bilayers that encapsulate rutin. Liposomal formulations enhance the stability and bioavailability of rutin, and provide controlled release. Solid lipid nanoparticles (SLNs) consist of solid lipids that can encapsulate rutin, improving its stability and permeability across skin layers in topical applications. Polymeric nanoparticles are made using natural or synthetic polymers, offering sustained and targeted drug release properties. Nanosuspensions can be dispersed in water or other solvents to form nanosuspensions, enhancing its dissolution rate and absorption. These nanoparticle formulations are often employed for topical applications, as they improve the penetration of rutin through the skin, enhancing its therapeutic benefits [2].

1.2 Therapeutic Role in Topical Diseases

Rutin offers several therapeutic roles in the management of topical conditions, primarily because of its anti-inflammatory, antioxidant and skin-protective properties.

1.2.1 Anti-inflammatory Effects: Rutin has been shown to reduce inflammation in skin conditions such as **eczema**, **psoriasis**, and **contact dermatitis**. It inhibits inflammatory mediators, such as prostaglandins and cytokines, thus providing relief from irritation and swelling [3].

1.2.2 Antioxidant Activity: The ability of rutin to neutralize free radicals contribute to the protection the skin from oxidative stress, which is crucial for preventing premature skin aging and conditions like sunburn and photoaging [4].

1.2.3 Wound Healing: Rutin promotes faster wound healing by stimulating collagen production and enhancing the regeneration of damaged skin. This makes it useful in the treatment of cuts, abrasions, and minor burns [5].

1.2.4 Skin Whitening and Anti-aging: The antioxidant properties of rutin help reduce pigmentation and protect against UV damage, aiding in skin whitening and providing anti-aging benefits [6].

1.2.5 Antibacterial and Antifungal Activity: Rutin has demonstrated antibacterial and antifungal properties, making it useful in the treatment of superficial skin infections.

Rutin is a valuable compound with significant therapeutic potential, particularly when formulated in nanoparticle forms for topical applications and its anti-inflammatory, antioxidant and skin-healing properties make it more effective for management of number of skin conditions, varying from inflammatory disorders to wounds and skin aging. Its use in nanoparticle formulations offers an advanced approach to improving its bioavailability and efficacy, making it a promising agent in dermatological treatments [7].

2. LITERATURE REVIEW

Martins *et al.,* studied and explored the enhancement of rutin's photochemopreventive effects by incorporating it into solid lipid nanoparticles (SLNs) for topical skin use. The SLNs, prepared using the hot melt microemulsion method, were evaluated in 3D skin models subjected to UVB radiation. The rutin-loaded SLNs displayed optimal characteristics, such as negative zeta potential, small particle size and high encapsulation efficiency. They effectively reduced UVB-induced skin damage by preventing both production of metalloproteinase formation and lipid peroxidation. These results indicate that rutin-loaded SLNs may be effective UV radiation protection agents [1].

Pozos-Nonato *et al.,* studied Nanoparticle-based formulations for anti-aging treatments are rapidly advancing due to their ability to target skin aging at the cellular and molecular levels. These next-generation nanoparticles, such as nanostructured lipid carriers, transfersomes, and ethosomes, offer superior performance compared to traditional carriers

by improving anti-aging compound's bioavailability, solubility and stability. Encapsulated ingredients like flavonoids, vitamins, and botanical extracts show improved skin rejuvenating effects, including moisturizing, antioxidant, and photoprotective benefits. However, further research is needed to assess safety, stability, and optimize large-scale production for clinical and industrial applications, ensuring these formulations' effectiveness and longevity [2].

Surendran *et al*.**,** studied that technique of ion gelation was implemented for the formation of nanoparticles of chitosan and alginate loaded with rutin (RCANP) having the ratio of 1.24:2:5 (rutin: chitosan: alginate). The RCANP4 formulation demonstrated favorable characteristics, the particle size was measured at 168.4 ± 12.24 nm, with 91.23 ± 1.1% entrapment efficiency and -24.7 ± 1.5 mV of zeta potential. The in vitro drug release was 88.89 ± 2.9% over 24 hours. FT-IR analysis confirmed rutin loading, while DSC showed a broad curve indicating rutin entrapment in the matrix. SEM and TEM revealed uniform, spherical nanoparticles. RCANP4 exhibited 3.54 times higher bioavailability than free rutin, enhancing its systemic circulation and antidiabetic activity. In diabetic rats, RCANP4 showed improved glucose control and significantly increased glucose uptake in HepG2 cells. Cytotoxicity studies indicated that RCANP4 reduced cell viability more effectively than free rutin, suggesting its potential for enhanced therapeutic outcomes [3].

Martins et al., studied that for synthesizing solid lipid nanoparticles loaded with rutin, method of hot melt microemulsion was used. These nanoparticles showed its improved photochemopreventive effect on the skin. To evaluate the ability of rutin SLNs to prevent UVB-induced damage such as sunburn of cells, activation of caspase-3, formation of metalloproteinase and lipid peroxidation, using two 3-D models i.e. engineered tissue and ex vivo skin explants. The SLNs had 74.22 nm size, high encapsulation efficiency (98.90%), and strong UVB protection in both models. Lipid peroxidation and metalloproteinase formation is also inhibited by Rutin SLNs, demonstrating their potential for topical photochemoprevention [4].

Li *et al*.,studied that antisolvent precipitation method was used to prepare Zein-carboxymethyl starch nanoparticles loaded with rutin. The maximum encapsulation efficiency recorded was 73.5% with zein-CMS-RT ratio set at 10:30:1, with nanoparticles of 196.47 nm in size and a 0.13PDI, strong dispersibility is indicated. Analysis using FTIR,

fluorescence spectroscopy, XRD techniques showed that hydrogen bonding, electrostatic interactions and hydrophobic forces played an important role in nanoparticle formation. SEM images revealed spherical particles, and particles embedded in a CMS cross-linked network at higher CMS concentration. The encapsulation of RT improved its thermal and pH stability, highlighting zein-CMS as an effective material for bioactive substance delivery [5].

Sharma *et al*., studied and prepared purified polyphenol-loaded nanoparticles containing gel formulation to accelerate healing of wound. Column chromatography is used to purify polyphenols, with HPLC confirming high content in the B fraction, which included quercetin, rutin, and tannic acid. Silver nanoparticles (AgNPs) were characterized and found to be non-toxic to L929 cells. The B fraction-AgNP gel showed improved stability and promoted wound healing in Wistar rats, with significant wound contraction and re-epithelization observed within 14 days. Histopathological and biochemical analyses supported the gel's efficacy. Molecular docking indicated strong interactions with PI3K and AKT receptors, indicating its potential as successful nano-drug delivery system to treat chronic wounds [6].

Cefali *et al*., evaluated a topical formulation comprising vegetable extracts loaded nanoparticles sought to test photostability, sun safety factor and physicochemical features. *Dimorphandra mollis , Ginkgo biloba, s, Vitis vinifera* and *Ruta graveolens* flavonoid-rich extracts were used to prepare nanoparticles of chitosan/tripolyphosphate, and incorporated into an oil-in-water emulsion. The nanoparticles exhibited 557.11 nm mean size, +11.54 mV zeta potential and 75.89% encapsulation efficiency. The formulation showed an SPF of 2.3, photostability, and efficient flavonoid release, suggesting its potential for moderate sun protection and skin benefits [7].

Memar *et al*., examined the antimicrobial impact of nanoparticles of mesoporous silica containing both curcumin and rutin. It is well known that both rutin and curcumin shows antibacterial, anti-inflammatory and antioxidant properties. Although, they shows poor efficacy because of low solubility as well as bioavailability. Nanoformulation improves their bioavailability. The results show that Cur-Rut-MSNs demonstrated a significantly stronger antibacterial effect compared to individual curcumin-loaded (Cur-MSNs) and rutin-loaded (Rut-MSNs) MSNs, against *Escherichia coli, Staphylococcus aureus,* and *Enterococcus*

faecalis ($p<0.05$). These results imply that a promising nanoformulation for treating bacterial infections may be Cur-Rut-MSNs [8].

Yadha *et al*., studied that Rutin having antioxidant, anti-inflammatory and antibacterial features, encounters challenges of low bioavailability and solubility. The conversion to silver nanoparticles using a Quality by Design (QbD) approach enhances its pharmacological potential. The optimized formulation (F12) demonstrated enhanced dispersibility, stability and displayed 126.3 nm average particle size. Laboratory studies demonstrated prolonged drug release (97.3%) and enhanced antioxidant and anticancer activity compared to rutin. Additionally, F12 demonstrated anticlastogenic potential by reducing micronuclei frequency in bone marrow cells, indicating its protective effects. These findings highlight Rutin silver nanoparticles as a promising lead for antioxidant, anticancer, and anticlastogenic therapy [9].

Saha *et al*.,studies has shown that delayed healing of chronic wounds and hypertrophic scarring in burns are caused by infiltration of immune cell, prolonged inflammation, free radical production, and overabundance of inflammatory mediators. This study developed rutin nanoparticles (RNPs) integrated into cryogels composed of eggshell membrane powder-cross linked gelatin-chitosan, aimed at reducing hyperinflammation. RNPs, with a size of 17.53 nm, were remained stable at ambient temperature and showed non-cytotoxicity. Their anti-inflammatory and antioxidant properties are demonstrated by reducing reactive oxygen species in human macrophages and increasing IL-10 levels. On the other hand, in fibroblast α-SMA expression is lowered by RNPs, indicating potential against scarring. Laboratory studies confirmed the biocompatibility of RNP-incorporated cryogels with superior re-epithelialization and enhanced wound healing compared to control groups. This method offers a feasible option to commercial dermoepidermal alternates that are deficient in anti-inflammatory and anti-scarring features. [10].

Gravandi *et al*.,investigated Rheumatoid arthritis (RA), persistent inflammatory illness that inflicts joint harm and antipsoriatic effects. Rutin has shown promising therapeutic benefits in these medical disorders. This study examined the protective effect of rutin nanoparticles that was triggered by Freund's complete adjuvant within an animal model suffering from rheumatoid arthritis. Sixty rats have been divided into various treatment groups and monitored for 28 days. Results showed that rutin nanoparticles improved behavioral

symptoms, modulated inflammatory markers like nitric oxide and GSH, and enhanced histopathological outcomes. The research findings indicate that rutin nanoparticles may be effective therapeutic strategy for managing RA [11].

Zhu *et al.,* studied oxidative damage and photocatalytic exposure to neurons is a key feature of Alzheimer's disease, leading to neuronal loss. Nrf2, a significant regulator of antioxidant effects and act as potential medicinal agent for the treatment of neurological disorders and also selenated rutin derivatives were prepared (Se-Rutin) using sodium selenate. This study investigated how Se-Rutin influences oxidative damage inH_2O_2-induced PC12 cells, focusing on expression of Nrf2 and concentration of reactive oxygen species. The findings indicated that selenated rutin derivatives lowered the level of reactive oxygen species and mitigated cytotoxic effects, it elevates Nrf2 and HO-1 expression levels but also outperforming pure rutin. This indicate that the anti-oxidative effects of selenated rutin may be mediated via Nrf2/HO-1 activation in Alzheimer's disease [12].

Lu *et al*., identified the flavonoid that possesses potent antioxidant and whitening properties and leading to development of niosomes loaded with flavonoid to improve stability, solubility and penetration into the skin. Several flavonoids were tested, with quercetin showing the best results in whitening and antioxidant activity. Niosomes prepared with Span60-RH40 at a 9:11 mass ratio formed stable vesicles with excellent entrapment efficiency (87.3%), improved solubility and photostability. In addition, quercetin-niosomes revealed an extended release capability and considerably improved transdermal absorption, achieving level of skin retention that was 2.95 times greater than solution of quercetin [13].

Alqarni *et al*., studied Candida spp. a major cause of fungal infections, often leading to hospital-acquired sepsis and high mortality rates. While polyenes and echinocandins are effective antifungal treatments, their long-term use can result in limitations. This study explores the antifungal potential of rutin, a compound with poor solubility. To enhance its efficacy, rutin was encapsulated in silver nanoparticles (SNPs) stabilized with gum acacia (GA), forming a novel nanocarrier system. The resulting SNPs, with a size of 59.67 ± 44.24 nm, possessed marked antifungal effect towards Candida albicans is implicated in skin candidiasis and it has exhibited excellent biocompatibility. This research highlights the potential of rutin-SNP gels in overcoming fungal drug resistance [14].

Memar *et al*., studied and demonstrates that nanoparticles of mesoporous silica containing rutin (RUT-MSNs) significantly enhance the antimicrobial properties of rutin. Due to rutin's poor bioavailability and solubility, the nanoparticle formulation improves its efficacy. RUT-MSNs exhibited cytotoxicity in HN5 head and neck cancer cells, inducing apoptosis and increasing ROS production. Additionally, RUT-MSNs showed improved antibacterial effects, with better performance in inhibiting bacterial growth compared to free rutin. These findings suggest that RUT-MSNs hold promise for the treatment of bacterial infections [15].

Saleemi *et al.,* explored that green synthesis technique was used to prepare rutin loaded zinc oxide nanoparticles and their properties were characterized to explore potential biomedical applications. Chemical and optical features of the prepared nanoparticles have been confirmed using FTIR and UV-Visible spectroscopy. SEM and TEM revealed their oval-shaped morphology and X-ray diffraction showed a wurtzite structure with 13.22 nm crystallite size. ZnO-R NPs exhibited lower antioxidant activity compared to pure rutin but demonstrated significantly better anticancer and antimicrobial properties as compared to pure rutin and standard ZnO NPs, with a lower IC50 in MCF-7 cells. Importantly, there is no significant toxicity exhibited by ZnO-R NPs toward *Artemia nauplii*, highlighting their potential as chemotherapeutic agents [16].

Li *et al*., investigated the interaction between rutin and gliadin with and without ultrasonication (0,150,300,450 and 600W) for 25 minutes, focusing on the functional characteristics of emulsions. Ultrasonication enhanced the gliadin-rutin interaction, increasing the β-type secondary structure and improving emulsion stability. Treatment at 450 W led to larger particle sizes and stronger emulsions with higher potential and storage modulus. However, 600W ultrasonication weakened emulsion stability. The results suggest that ultrasound treatment of G-R complexes is an effective method to alter protein structure and produce stable emulsions, with potential applications in the food industry for improving texture and stability [17].

Moldovan *et al*., aimed to investigate the impact of nanoparticles of gold reduced by Rutin (AuNPsR) on cataracts (CA) and diabetic retinopathy (DR) in a rat model suffering from diabetes. Diabetic conditions led to constriction of retinal arteriolar, inflammation and oxidative stress, resulting in thickening of retina and opacity of lens. Rutin lower the oxidative stress, increase diameter of retinal arterioles and inflammation, while insulin

worsened the health of retina. AuNPsR produced the best results such as enhancing the appearance of retinal arterioles, lowering the oxidative stress and increase antioxidant efficiency; however some lens disorganization and retinal edema are remained. This study advised that AuNPsR may be an impactful therapeutic approach towards DR and CA [18].

Gali *et al*., study involved encapsulating extract of a rutin derived from *Ruta chalepensis L.* in nanoparticles loaded with zein and it target to overcome the low bioavailability and solubility of rutin. The nanoparticles that are stabilized by use of gum Arabic (GA) showed enhance stability, with GA improving encapsulation efficiency and facilitating quick breakdown during stimulated digestion processes. The outcomes revealed that GA/zein nanoparticles are a promising way to deliver natural extracts, featuring a straightforward and efficient fabrication method [19].

Gao *et al.,* studied Conventional medications for hepatocellular carcinoma are limited by adverse effects and poor efficacy. However, black mulberry leaves loaded with lipid nanoparticles MLNPs, are abundant in proteins, glycolipids and active compounds like quercetin 3-O-glucoside and rutin. In vitro, MLNPs selectively targeted liver tumor cells, inducing oxidative stress and mitochondrial damage, which inhibited cell viability, migration, and invasion. In vivo, oral MLNPs showed minimal side effects and effective anti-tumor activity, suggesting their potential as a safe and effective treatment for hepatocellular carcinoma [20].

Dizaj *et al*., investigated to develop nanoparticles mesoporous silica co-loaded with curcumin and rutin (Cur-Rut-MSNs) and evaluate their physical and chemical properties, cytotoxicity, and ROS generation in HN5 cancer cells of neck and head . Both rutin and curcumin are promising anticancer agents, but their low solubility and bioavailability limit their effectiveness. The outcomes revealed that the Cur-Rut-MSNs had a structure that is mesoporous in nature, negative surface charge, nanometer size, with X-ray diffraction indicating they belong to the MCM-41 silicate family. The cytotoxicity of Cur-Rut-MSNs is greater than individual curcumin or rutin containing nanoparticles. These findings suggest that Rut-Cur-MSNs could serve as a good nanoformulation for treatment of cancer [21].

Alowaiesh *et al*., studied that silver nanoparticles are produced by valorizing olive waste with silver nitrate, which demonstrated enhanced antioxidant properties. OLAgNPs, with a size of 29 nm, showed a 42% increase in total phenolics and a 50% increase in flavonoids

compared to the parent extract. The nanoparticles exhibited superior antioxidant activity, with an SC50 of 5 µg/mL, and contained higher levels of key phenolic compounds. OLAgNPs also displayed significant anticancer effects, inhibiting the growth of three cancer cell lines by 79-82%, and expressed antibacterial effect towards bacteria. These findings suggest silver nanoparticle loaded with olive as an effective candidate for mitigating oxidative stress, cancer, and MDR pathogens [22].

Alidoust *et al*., studied the antivirulence characteristics of nanoparticles of zinc oxide that were linked with rutin towards *Staphylococcus aureus* and *Pseudomonas aeruginosa*. The zinc oxide nanoparticles loaded with rutin were analyzed by many techniques, indicating 161.7nm average size with -35.3 mV surface charge. The nanoparticles of zinc oxide loaded with rutin exhibited stronger antibacterial and hemolytic inhibition compared to individual rutin and zinc oxide nanoparticles. Moreover, they decrease the quorum sensing genes expression (lasI, rhlI, agrA) and inhibited pyocyanin production in *P. aeruginosa*. These outcomes highlight the potential of zinc oxide nanoparticle loaded with rutin as efficient antivirulence agents against pathogenic bacteria [23].

Alshahrani *et al*., focuses on the development of a rutin-loaded nanoemulsion (NE-RU) using Labrafil® M 1944 CS as oil phase, Transcutol P as co-surfactant and Tween 80 as surfactant. Optimization was done using a central composite design with three levels, yielding a formulation characterized by 98.53 nm droplet size, -46.70 mV zeta potential and drug loading of 92.34 %. Compared to the naive form, NE-RU exhibited significantly improved dissolution (25.55-fold), permeability (1.98-fold), and oral bioavailability (33.68-fold). Stability studies expressed minimal differences in zeta potential, particle size and drug loading between fresh and aged formulations. These findings suggest NE-RU could be a promising candidate for exploring pharmacodynamics in oxidative stress-related metabolic disorders [24].

Wu *et al*., studied Rutin, a flavonoid that may offer benefit in treating brain injuries and Alzheimer disease, is hindered by its incapacity to penetrate the blood-brain barrier, low solubility and restricted bioavailability. Rutin liposomes modified with transferrin (Tf-Rutin-Lip) were prepared to enhance these aspects. The optimized preparation conditions, including particular a specific drug-to-lipid ratio, lipid-to-cholesterol ratio and other factors. Toxicity tests showed no adverse effects on brain endothelial cells, and Tf-modified

liposomes successfully crossed the BBB. Pharmacokinetic studies demonstrated a significant increase in Rutin's bioavailability, suggesting that Tf-Rutin-Lip enhances brain-targeting and could improve Rutin's efficacy in treating brain disorders [25].

Aftab *et al*., elaborate the function of carbopol gel loaded with silver nanoparticle improve wound healing in a rat model suffering from diabetes. Methanolic extracts obtained from *Mentha longifolia, Mentha spicata* and *Mentha piperita* have been used to prepare nanoparticles of silver and these nanoparticles were analyzed using XRD, FTIR, SEM and UV-Vis spectroscopy. The study assessed antioxidant, antiglycation and antimicrobial activities, with MP.AgNP exhibiting the maximum antioxidant (88.55%) and antiglycation (83.3%) potential. Histopathological determination in diabetic rats revealed that MP.AgNP-loaded Carbopol gel facilitated 100% wound closure by day 20, with faster re-epithelialization compared to controls. The results demonstrate that MP.AgNP-loaded Carbopol gel is a promising, safer, more efficient and effective treatment for diabetic wound healing [26].

3. RESEARCH GAP IDENTIFICATION

The development of rutin nanoparticle-based topical formulations presents a promising solution to overcome the limitations of conventional rutin applications, including poor bioavailability, limited skin permeability and inadequate multifunctional efficacy. Existing gaps in nanoparticle design, skin compatibility and the integration of antimicrobial, antioxidant, antipsoriatic and photocatalytic properties highlight the need for innovative approaches. Addressing these challenges through green synthesis and comparative studies with conventional formulations can enhance therapeutic potential and align with sustainability goals. This research focuses on creating a safe, effective and multifunctional rutin nanoparticle-based topical system for clinical applications.

4. OBJECTIVES

1. Synthesis and Characterization of Rutin Nanoparticles (RNPs): To synthesize rutin-loaded nanoparticles using various methods such as solvent evaporation, co-precipitation, or emulsification techniques. To evaluate the physical and chemical characteristics involves assessing parameters such as particle size, zeta potential,

morphology utilizing methods like SEM, TEM, encapsulation efficiency, the profile for drug release and stability under diverse conditions.

2. Development and Evaluation of Topical Formulation: To develop a topical gel or cream incorporating RNPs, ensuring stability, homogeneity and optimal viscosity for effective skin penetration.
3. To assess the Biological activities:
    - Antimicrobial potential of the formulated RNPs against common skin pathogens, including bacteria and fungi, using appropriate in vitro models.
    - In Vitro antioxidant activity will be evaluated using standard in vitro DPPH (2,2-diphenylpicrylhydrazyl) radical scavenging and reducing power assay.
    - In vitro and In vivo Antipsoriatic activity: In vitro evaluation of antipsoriatic effect of the extracts will be conducted using 3-(4,5-dimethyl-2-thiazolyl)-2,5-diphenyltetrazolium bromide (MTT) assay, which involve the use of HaCaT cells. In vivo antipsoriatic activity will be evaluated using Optimized topical formulation using a mixture of formaldehyde and CFA.
    - Photocatalytic Activity: To examine the photocatalytic activity of rutin nanoparticles subjected to ultraviolet or visible light exposure, with a focus on their potential uses in phototherapy and wound healing.

5. PROPOSED METHODOLOGY

5.1. Synthesis of Rutin Nanoparticles: The rutin nanoparticles will be synthesized by selecting appropriate biodegradable polymers like PLGA (poly (lactic-co-glycolic acid)), chitosan or lipids to encapsulate rutin, ensuring improved stability and controlled release [8].

5.2. Characterization Techniques: The prepared nanoparticles will be characterized through Dynamic Light Scattering (DLS) to assess particle size; both Transmission Electron Microscopy (TEM) and Scanning Electron Microscopy (SEM) are used to analyze surface morphology and Fourier Transform Infrared Spectroscopy (FTIR) for assessing functional groups. The encapsulation efficiency will be calculated using a UV-Vis spectrophotometric method and drug release studies will be conducted using a dialysis bag method [9].

5.3. Formulation of Topical Gel: The RNPs will be incorporated into gel or cream formulations using a gelling agent like carbopol or hydroxyethyl cellulose. The formulations will be optimized for consistency, spreadability and skin penetration [10].

5.4. Biological Evaluation:

5.4.1. In vitro Antimicrobial Activity: Antimicrobial activity will be evaluated using standard microbiological methods like disk diffusion, broth microdilution assay and zone of inhibition methods [11].

5.4.2. In vitro Antioxidant activity: The DPPH (2,2-diphenylpicrylhydrazyl) radical scavenging and reducing power assay will be used to assess in vitro antioxidant effect[12].

5.4.3. In vitro Antipsoriatic activity: To assess the extract's antipsoriatic effect in vitro the 3-(4,5-dimethyl-2-thiazolyl)-2,5-diphenyltetrazolium bromide assay (MTT) will be used, which involve the use of HaCaT cells [13].

5.4.4. **In vivo Antipsoriatic activity:** Antipsoriatic activity will be evaluated using Optimized topical formulation using a mixture of formaldehyde and CFA [14].

5.4.5. Assessment of Photo catalytic Activity: By exposing the RNPs to UV/visible light and monitoring the degradation of a model dye like methylene blue to evaluate their photocatalytic efficiency [15].

5.5 Expected Outcomes:

5.5.1. Enhanced Solubility and Bioavailability: The synthesized rutin nanoparticles are expected to significantly increase the solubility and bioavailability of rutin, resulting in enhanced therapeutic effects.

5.5.2. Effective Topical Formulation: The developed topical formulation will demonstrate stability, ease of application and enhanced skin penetration of the active ingredient.

5.5.3. Enhanced Antimicrobial, Antioxidant and Antipsoriatic Activities: The Rutin-loaded nanoparticles are anticipated to exhibit significant biological activities against common skin pathogens, proving their potential as an effective treatment for skin infections.

5.5.4. Photocatalytic Potential: The research will establish rutin nanoparticles as a potential candidate for photocatalytic applications, enhancing wound healing and skin protection through UV light exposure.

6. THESIS OUTLINE

Tentative chapter wise scheme of the proposed work is as follows:

Chapter 1: Introduction

This chapter aims to provide a brief overview of the Rutin, along with a discussion of procedures and work plan that will be elaborated upon.

Chapter 2: Literature Review

This chapter will provide a detailed account of the rutin's physicochemical and pharmacological profile, excipients and review of literature on the selected plant materials and will also include research gap identification.

Chapter-3: Material and Methods

This chapter will contain the following details:

1. Regarding selections of various methods.
2. Pre-formulation study of the selected plant materials.
3. The detail regarding the material used.
4. In vitro screening methods such as antimicrobial, antioxidant, antipsoriatic and photocatalytic activities.

Chapter-4 Results and Discussion

This chapter will tabulate, analyze and discuss the findings of various studies.

Chapter-5 Summary and Conclusion

Ph.D. work will explore the synthesis, characterization, and formulation of rutin-loaded nanoparticles for enhanced antimicrobial, antioxidant, antipsoriatic and photocatalytic activities. The study aims to develop a novel topical formulation that can be effectively utilized for skin infections and phototherapy, contributing to advancements in nanomedicine and topical drug delivery systems.

Chapter-6 References

The reference list's entries comprise of four essential components: the author, the date, the title and the source.

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CERTIFICATE

(SYNOPSIS APPROVAL CERTIFICATE)

This is to certify that the Synopsis for Ph.D. Thesis titled, **"Rutin Nanoparticles-Driven Formulation for Enhanced Biological and Environmental Applications"**, submitted by **Mr. Deep Sharma** to the Career Point University, Hamirpur (H.P.), India in partial fulfillment of the requirements for the degree of **DOCTOR OF PHILOSOPHY** in the **Department of Pharmacy, School of Pharmaceutical and Health Sciences, Career Point University, Hamirpur** has been approved by the Research Advisory Committee (RAC) after an Oral Examination of the student on dated 10-02-2025.

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